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Status of Storage Programme 1997-2000

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Abstract

In Denmark, the development of seasonal storage is closely related to the development of large-scale solar heating. Activities not related to this context are not presented in the following due to lack of insight by the author.

A large share of solar in a total heating system demands the presence of large-scale thermal storage capacities. This is the case for renewable technologies in general due to the natural fluctuation of such sources. Low-cost solutions must be found if renewables are to be applied in a larger range in the next years and even more if the non-renewable sources lead to crisis in the years to come. The Danish Energy Agency (DEA) is administrating a development programme for seasonal storage, launched in 1997. An expert group is acting as advisers to the DEA and defines the programme to be sanctioned by the solar energy board and last but not least the DEA. The programme and the achieved advances are described in this paper, followed by a description of ongoing activities and planned goals.

Introduction

Background

The development of large-scale solar heating requires large thermal storage capacities. In the past, the development of such storage was provoked by the energy crisis in the early 70s and was closely related to the vision of a world getting its energy from renewable resources, mainly the sun. At the newly established Thermal Insulation Laboratory[1] at the Technical Highschool of Denmark, Prof. Vagn Korsgaard and his staff created the '0-Energy House', including a very large seasonal storage in form of a strongly insulated steel tank, buried outside the building. They also worked with insulation techniques, solar heating, measurement methods and not irrelevant for this paper, the first experimental seasonal storage of 'larger scale'. At this stage the development was purely academic. A few years later consultants and enterprises were dominating, but still co-operating with academic partners. In the early days, no Ministry of Energy had been established and the activities were administrated by the Ministry of Trade. In recent days the Danish Energy Agency is the central authority co-ordinating and financing the activities.

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[1] Today: Department for Buildings and Energy (IBE), Technical University of Denmark (DTU).

The History of Seasonal Storage in Denmark

The first seasonal storage in Denmark was designed and built at DTU for experimental purpose. The storage was designed as a pit water storage with floating lid between 1990 and 1993, (NANSEN K.K. et al.1993) and (USSING V. 1991). Since that time the development of seasonal storage was, on the one hand, rather oriented to the goal of finding a reliable and economical solution, on the other hand the search for solutions was not restricted to any particular technology. After preliminary investigations some technologies were considered irrelevant in the first case, among others chemical and geothermal. Others, receiving great recognition in other parts of Europe, the UTES-technologies were, in a later stage, evaluated to be less relevant, partly due to lack of reliable economical indications and partly due to the geological conditions of Denmark with rather strong ground water flows.

In 1990 an attempt was made to apply prefabricated concrete elements, normally applied for liquid manure from farming, (WESENBERG C. 1990). The 500 m^3 Hoerby storage, sealed by a bentonite-concrete coating inside, showed severe leakage due to cracks at the element joints (PEDERSEN V.P. 1992). An attempt was made in 1990 to seal the storage, however with no success, (WESENBERG C. 1993). The prefabricated concrete element storage was found unreliable.

In 1991 the DTU-storage from 1990 was re-constructed into the first gravel or earth-pit storage, (USSING V. 1991). No final conclusion could be drawn from this experiment, but rather promising construction procedures were developed together with the successful demonstration of the floating lid concept and involved materials.

Motivated by the expectation of a successful technology transfer, a 3,000 m^3 storage was built in Herlev (Tubberupvaenge) in 1991 by driving steel sheet piles into the earth, digging the inside material out, insulating the pit with polyurethane-plates and tightening the pit with an EPDM rubber membrane. The installation was complex and the operation showed severe water loss.

All in all we can conclude from the experiences from the Hoerby and the Tubberupvaenge storage that solutions based on the application of prefabricated elements have not been successful.

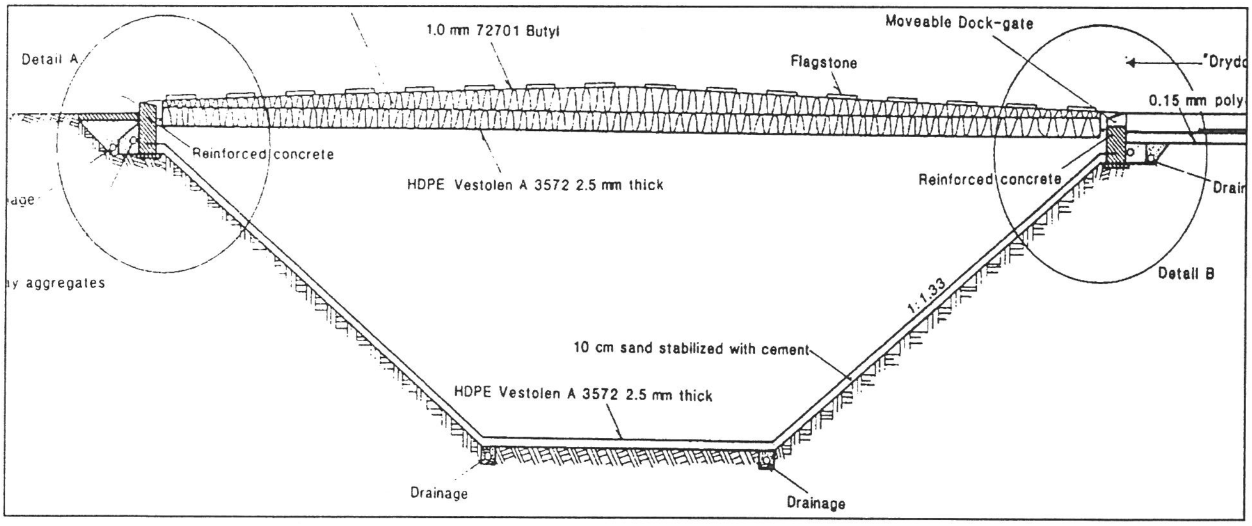

Figure 1 Cross section plot of the Ottrupgaard pit design.

In 1995, a pit water storage with floating lid was constructed to serve a small central solar heating plant at Ottrupgaard, Skoerping. The 1,500 m^3 pit, shown in Figure 1, and experiences will be presented in detail by the author at the conference. The pit hole is sealed by a hybrid liner of polymer-sheets, clay covered by a geo-textile and concrete stones to avoid erosion of clay into the storage water. The total construction cost led to a volume price of approximately 200 Euro/m^3, which is much above the aimed 35 Euro/m^3 for large-scale storage of the future. The pit showed severe water losses and a solution had to be found.
Based on the experience from a large number of techniques, the contents of the 'Seasonal Storage Programme 1997-2000' were defined within the "Programme for the Development of Renewable Energy Sources" (UVE) under the Danish Energy Agency.

The Seasonal Storage Programme 1998-2000

In 1997 four different renewable energy technologies amongst the seasonal storage technologies were chosen to be pushed ahead. Over a four-year period the subjects were supported with a total of 14 mill. Euro (100 mill. Danish Kroner) to be allocated and administrated by the Danish Energy Agency. Right after the surprising news, the expert group in seasonal storage was called to define a work programme. The goal of the programme was defined as:

- in co-ordination with solar heating to be able to demonstrate a fully pollution-free heating method, economically competitive with conventional fossil fuel, including environmental impact in the economical calculations.
- to be able to offer a storage technology for the regulation of an integrated energy system with a large share of renewable energy sources.

As we see, the programme was and still is rather ambitious. The objectives were translated into the following subjects and activities for the first period 1997-1999, defined in a "Plan of Action for Storage and Regulation", (SØRENSEN P.A. 1998) with a budget of 0.7 mill. Euro a year:

- From 1998 to 1999 problems with pit water storage are to be solved, resulting in a final design to be implemented in the two years with 35% financial support from the programme. Among other things, lid solutions must be found, PP-liners tested and the Ottrupgaard pit re-established.
- Investigation on realisation of large-scale steel-tanks solutions is planned in 1999 and a large-scale long-term storage built in 1999, supported with 20% by the programme.
- Designing and establishing a pit gravel-pipe storage and following monitoring programme from 1998 to 2000.
- Minor activities regarding building-integrated storage technologies and others.

Activities and findings

After the first programme phase we can conclude that the programme activities are keeping track and leading to results as aimed.

Steel-pile storage with steel sheet liner

After years of supplementary investigations and trials to place the responsibilities for the leak at the Tubberupvaenge storage, the storage was tightened in 1996. The final solution is a 0.5 mm sea-proof, stainless steel liner of type 254

SMO at bottom and side, and a SS 2343 steel liner at the roof, (WESENBERG C. 1998). Minor water losses were observed also after the installation of the steel liner. Divers found the leak and could weld it. Now the pit is tight and in use. Based on this episode a complete construction and control procedure is developed for stainless-steel liners and costs are exposed in realistic terms. The final steel-liner solution for pit tightening is estimated at 80 Euro/m^2 storage volume, whereas the material cost accounts for 15 Euro/m^2. Hence construction procedure must be optimised to lower this price. This seems not realistic due to the fact that highest experiences were utilised in the development of the mentioned procedure.

The pit water with hybrid clay liner

A solution for the pit water storage in Ottrupgaard is found and the re-establishing put into work. The activities will be presented by the author at the conference. Results are expected for the spring or summer of 2000. The lid project chain is at the point where a polymer based solution is stopped until the life-time of polymers under the conditions of thermal storage is proved, and at present a stainless steel-liner solution is under construction to be tested at the Technical University of Denmark this year. A final design for pit water storage is expected in the spring of 2000. Solutions based on metallic solutions are expected at a price near 80 Euro/m^3 and with polymer liner materials at prices down to 3 Euro/m^3.

Gravel storage with pipe heat exchanger

A gravel storage with pipe heat exchanger, shown in Figure 2, is designed and established at the central solar heating plant in Marstal, Denmark, and taken into operation in the spring of 1999 and working as expected. The design was inspired by the similar storage at the ITW in Stuttgart.

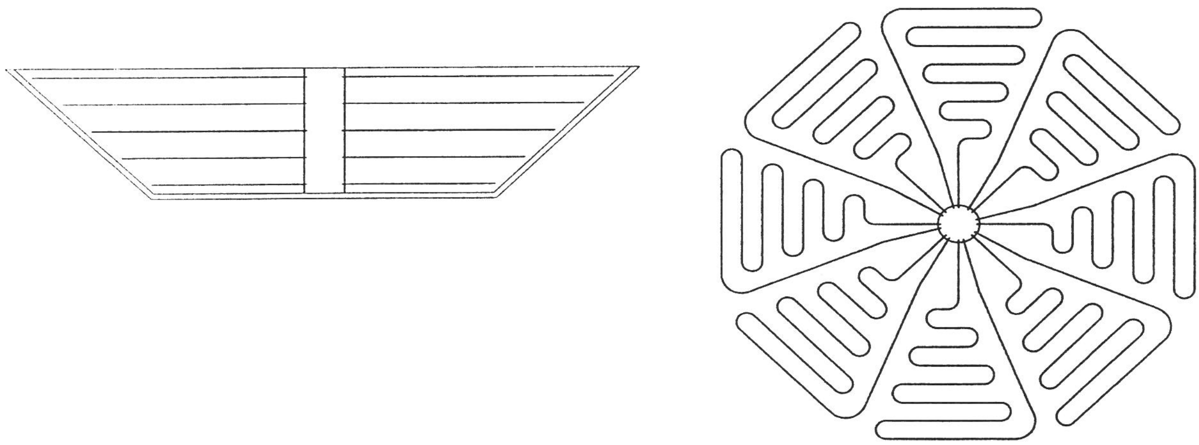

Figure 2 Basic gravel storage design. Left: The pit with storage material and pipe heat exchanger in layers. Right: Pipe heat exchanger lay out.

The gravel storage, with a volume of 3,500 m^3, consists of layers with gravel material and layers with sand material. 5,000 metres heat pipes of PEX polymers are placed in the sand layers as shown in Figure 2 to the right (sand for protection). The whole pit is filled with water from the bottom, where a stone layer ensured distribution of water to the whole storage. This was done parallel to the filling of the store with gravel and sand material. Experiments with filling the store from the top have shown severe problems with air bubbles. Hence the procedure applied in Marstal is strongly recommended.

The design was, in respect to the length of pipes to be chosen for heat exchanging, partly based on experiments carried out at the Technical University by (MAURESCHAT et al. 1999). Here the heat transport for pipe heat exchangers was measured for different sand materials. Temperatures were measured in and around the pipe. Maximal heat transfer rates of 180 W/m pipe were measured for cold storage conditions. The draw-off shows even lower heat transfer rates of maximum 70 W/m. It was also observed that no convection could be measured for the sand material to be applicable at the store. A monitoring programme is ongoing at the Marstal gravel store and the first results are expected soon.

At this point we can already conclude: The solution gives an opportunity of using the storage area for other purpose than heat storage. Monitoring shows that the low heat transfer rate for the system results in very low maximal temperature in the storage measured to 66°C in 1999, when 80°C was expected. This is in good agreement with the findings of the experimental work. Due to this slow thermal performance, the application of gravel storage of the given type cannot be recommended for high-temperature storage. Hereby application of low-price polymer liners is reliable for gravel storage. The total price for the Marstal store is 0.9 mill. Euro, which is 255 Euro/m^3 storage capacity, approximately 2000 m^3 water equivalent. As we find, the price is even higher than the Ottrupgaard pilot pit water storage. Hence even though low-price lining is reliable the gravel storage technology cannot compete with pit water storage by neither price nor thermal performance.

Other activities

No activities have been in the field of steel-tank storage. Anyway a demonstration of a large scale steel-tank storage is planned for seasonal storage.

In the field of building-integrated storage, a status for building integrated sand storage is prepared and investigations on hypocaust-solutions in walls, floors and foundation constructions are ongoing. A status project is ongoing in the field of mass stove technology with building integrated mass storage.

Outlook

Working in the direction of the first phase of the seasonal storage programme, a second plan of action is put into operation in the autumn of 1999, (SØRENSEN P.A. 1999). With a similar yearly budget as in the previous phase, the following activities are planned:

- The Ottrupgaard pit water storage will be re-established and one or two floating lid designs tested under real conditions at DTU. Hence the pit water concept is expected finalised in at least one design to be established in a scale of approx. 5000 m^3 in the next years. Projects for the realisation are founded and under development.
- Work on development and proving of temperature resistant polymer liners is initialised and is expected to bring solutions in the time to come.
- The monitoring programme for the Marstal gravel storage is ongoing and extended to the following year. A final report is expected in this phase.

- Establishment of a large steel-tank for seasonal application is under design for two independent projects in co-ordination with the pit-water storage activities. None has been built yet.
- Application for a full-scale extension of the Marstal plant with seasonal storage is placed at the European Union with rather realistic response. So the realisation of a 4,000 up to 10,000 m^3 pit storage will be realistic within a few years.
- Activities in building-integrated storage are ongoing and will, from an overall point of view, give us the basic knowledge for the design of integrated constructions and solutions and tools to execute the relevant calculations and simulations.

Summary

The history of seasonal storage in Denmark is filled with examples that show severe problems with the tightness of such solutions. One problematic example followed the other. Attempts to use prefabricated element solutions disappointed for both pit sealing and lid constructions. In spite of all these doubtful results, the work led to stepwise progress and was, supported mainly by the Danish Energy Agency and the involved actors, devoted to finding solutions to the problem. The problem as such seems so simple, namely keeping hot water in a 'large bottle', but turns out to be so demanding and tricky. Anyway, in the recent month things seem to show the first signs of a successful story. It seems realistic to design steel-liner solutions in both pit sealing and lid design. The polymer solutions would be economically superior, but latest results showed severe lifetime problems for the materials, and also the lifetime test procedures. The reason being the conditions the liners are exposed to, hot water on one surface and air on the other. Rather simple actions could solve the problem if the industry shows interest in the subject. If the industry is not involved no solution will be found for years, except by accident.

A conclusion cannot be made. The steel-tank is a reliable but expensive and visually polluting solution with many years of experiences related to it. Aquifer and underground stores only seem applicable in some places in Denmark, but the documentation behind this conclusion is rather limited and the future will show if that is the case. Pit water storage with steel-liner will be realised in the next few years and we will get results soon. The corresponding polymer-designs seem to lack in reliability. Gravel storage shows very slow thermal dynamics, but final conclusions are on the way. All in all, we seem to be on the right track and will have reliable, low-price solutions already in the coming few years.

Acknowledgements

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References

HANSEN, K.K., HANSEN, N.P. & USSING, V. (1993) Seasonal Heat Storage in Underground Warm Water Store, Construction and testing of a 500 m^3 store, Meddelelse, nr. 134, Thermal Insulation Laboratory, Technical Highschool of Denmark.

MAURESCHAT G. AND HELLER A. (1999) Modelforsøg: Varmetransport og effektafgivelse i grus. Experiments with heat transfer in gravel materials. Special Topics, SR-9716, Department of Buildings and Energy, Technical University of Denmark.

PEDERSEN, V.P. (1992) Målinger og evaluering af varmeakkumuleringstank i Hørby, Measurements and evaluation of thermal storage tank in Hoerby, Nr. 92-10. Cenergia Energy Consultants, Thermal Insulation Laboratory, Technical Highschool of Denmark and Folkecentret for VE, Ballerup, Denmark.

SØRENSEN, P.A. (1998) Handlingsplan for lagring/regulering 1998-2000, Plan of Action for Seasonal Storage and Regulation, Unpublished work.

SØRENSEN, P.A. (1999) Handlingsplan for lagring/regulering 1998-2000, Plan of Action for Seasonal Storage and Regulation, Unpublished work.

USSING, V. (1991) Forsøgborehulslager og ombygning af damvarmelager til gruslager, Bore Hole Storage and Reconstructioning of Pit Water Storage to Gravel Storage, nr. 219, Thermal Insulation Laboratory, Technical Highschool of Denmark, Building 118, DTU, 2800 Lyngby.

WESENBERG, C. (1990) Skitseprojekt. Sol til sommerstop i eksisterende halmvarmeværk - Forsøgsanlæg, Sketch, Solar for existing straw heating plants - Pilot plant, Nellemann Consultants, Denmark.

WESENBERG, C. (1993) Undersøgelse og udbedring af varmeakkumuleringstank udført i beton (Hørby-tanken), 1990-1993, Investigation and reconstruction of Thermal Storage Tank in Concrete (Hoerby Storage), Nellemann Consultants, Aalborg, Denmark.

WESENBERG, C. (1998) Rekonstruktion af Tubberupvaengetanken, Del 2: Bygning og driftssættelse, Reconstruction of Tubberupvaenge Storage: Part 2: Building and Operation Start, NNR Consultants, Odense, Denmark.